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Guidance for Orbital Module Recovery

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Abstract

Payloads in orbits working under microgravity conditions need to be ecovered safely at a specified location in Earth. A guidance scheme during thrusting phase of the mission, to recover a module from Low Earth Orbit, for a ballistic Entry is described in this paper. Module will be de boosted by RCS thrusters till entry point of 80km and will be recovered through ballistic re entry. Guidance scheme for the mission is to orient the vehicle till atmospheric entry point, ensuring minimum dispersions in down range and cross range at touch down.

Introduction

Mission to recover a module from a Low earth orbit is planned to have three phases namely, orientation phase where the vehicle will be oriented to the desired orientation for deboost, a de boost phase where the module is brought to 80km altitude using RCS thrusters and the last phase of the mission is the atmospheric phase where it is planned to recover through a ballistic trajectory.

Guidance for the mission is to orient the vehicle such that at atmospheric entry point, the vehicle is at the pill box which ensures minimal dispersions at touch down point. Guidance algorithm for the mission is divided into two phases as, guidance during orientation phase where guidance predicts the required orientation for de boost motor firing and also orient the vehicle to the predicted value, and a closed loop scheme to orient the vehicle during de boost firing such that at entry point vehicle states are at pill box which minimizes the touch down point range uncertainty .

A guidance algorithm is described in this paper for the de boost phase of the mission which computes the steering commands and also the required coast duration on line in between de boost firing to achieve the specified longitude and latitude at entry which minimizes the range dispersions at touch down.

Phases of Recovery mission

The mission is to recover a module safely from a low earth orbit. Hence phases of mission are

Orientation phase : Vehicle is oriented to the desired direction for de boost

De boost phase : De boost the vehicle upto entry point using RCS thrusters.

Entry phase : Vehicle follows a ballistic trajectory during atmospheric phase.

Phases of Guidance

Having ballistic entry during atmosphere, in order to achieve the mission with touch down point minimal dispersions, we have to ensure the entry conditions to be at pill box. Hence the closed loop guidance scheme shall have the following phases.

Orientation phase: Scheme to predict the required orientation at de boost ignition depending upon the initial conditions

De Boost Phase : Small RCS thrusters are used for de–boosting the module to a pill box.

Guidance Algorithm for SRE

Vehicle shall be oriented to a pre fixed attitude for de boost motor firing which is derived from ground simulations to achieve the required range at shut down. But this may result into less optimum de boost firing and may also call for high command rates during de boost guidance to achieve the required range at touch down due to dispersion in initial orbit. This may be avoided by computing the required orientation at de boost on ground using the orbital information and commanding the vehicle from ground. A closed loop guidance scheme shall also be used to predict the optimum orientation on line which reduces the fuel consumption and also the rates during de boosting.

A velocity to be gained scheme which basically work on cross product steering is developed for de boost phase to achieve the required states at the end of thrust which minimizes the range dispersions.

De Boost Phase Guidance algorithm

Algorithm during de boost phase is to orient the vehicle during de boost firing such that vehicle is at pill box at the end of de boost even under vehicle dispersions. In order to ensure all the states at pill box so as to minimize the range dispersions at touch down a velocity to be gained scheme with an on line predicted coast in between thrust is developed. Schematic of the constraints during de boost is given in fig(1).

Velocity to be gained scheme

Algorithm finds the required velocity to reach the states at the end of de boost motor firing. Knowing the vehicle present velocity and the required velocity to reach the required ellipse, algorithm calculates the velocity to be gained to reach the specified conic. Steering commands are generated from cross product steering

i.e., $$\omega = a_T * Vg$$

where ω is the body rate , a_T is the vehicle acceleration & Vg the velocity to be gained. The targets to achieve the conditions at the end of de boost are selected from an optimal trajectory generated on ground. The targets selected are the apogee radial distance(Rd) and angular momentum(Hd) of the ellipse. Required velocity is computed as

Required velocity along horizontal is

$$Vrh = Hd / r$$

Required velocity along radial is

$$Vrv = \sqrt{\frac{\mu}{r} * [2 + \frac{r}{Rd^2} * (\frac{Hd^2}{\mu} - 2Rd)] - Vrh^2}$$

where r is the instantaneous vehicle position. Knowing the vehicle present velocity, velocity to be gained is calculated as

$$\bar{Vg} = \bar{Vr} - \bar{V}$$

Steering commands are generated from cross product steering.
A block schematic of Vg scheme is given in fig:(3)

Implementation of Vg Guidance

Co ordinate system - Co ordinate system is selected as the De boost point Inertial system.(fig:2)

Vg- scheme is integrated with a simulation program developed in MATLAB. Scheme is validated for nominal and off nominal thrust. Table-1 gives the dispersion in range achieved at touch down for variation in thruster performance. It is observed from the results that range dispersions are high as the thrust perturbation increases.

Vg Guidance with angle to go constraint

Since apogee and perigee of the ellipse to be achieved are specified, the Vg guidance scheme ensures the correct velocity and flight path angle at entry point, but the latitude & longitude at injection are not specified . This makes dispersion in range.

Inorder to achieve the correct range, angle to be covered during de boost also to be specified as a constraint, so that vehicle is at correct longitude & latitude at entry.

During simulations it is observed from earlier section results that different coast duration is required to achieve the required range for different vehicle perturbations. An algorithm is developed to compute the angle to be covered after a specified duration of de boost motor burn to compute the angle to be covered and the coast duration.

After 700sec of de boost firing, algorithm computes the angle covered and compare against the nominal value which is obtained from an optimal trajectory for nominal vehicle performance. The coast duration required is calculated from a third order polynomial curve of coast duration versus the difference in angle covered stored on board. Fig(4) gives coast duration versus angle deficiency.

Second ignition command for de boost firing is initiated at the end of coast. Command updation using Vg scheme is continued during second burn, till the end conditions are reached . De boost thrust firing end command is generated by guidance once the entry conditions are reached.

Simulation Results

Vg Guidance with angle to go constraint is integrated in a 3-D trajectory program and is validated under vehicle nominal and off nominal conditions. Dispersion in range achieved is given in Table- 2.

Conclusion

A closed loopguidance scheme for deboost phase of the mission is developed and validated
for a recovery mission to recover payloads from orbit.

Simulation results for different vehicle performance show that Vg guidance scheme with angle to be covered constraint meet the mission specifications accurately.

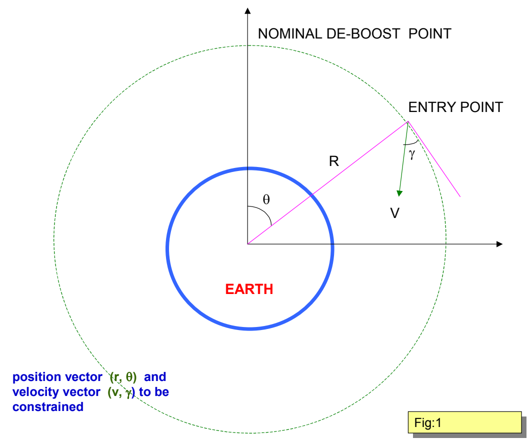

Fig:1

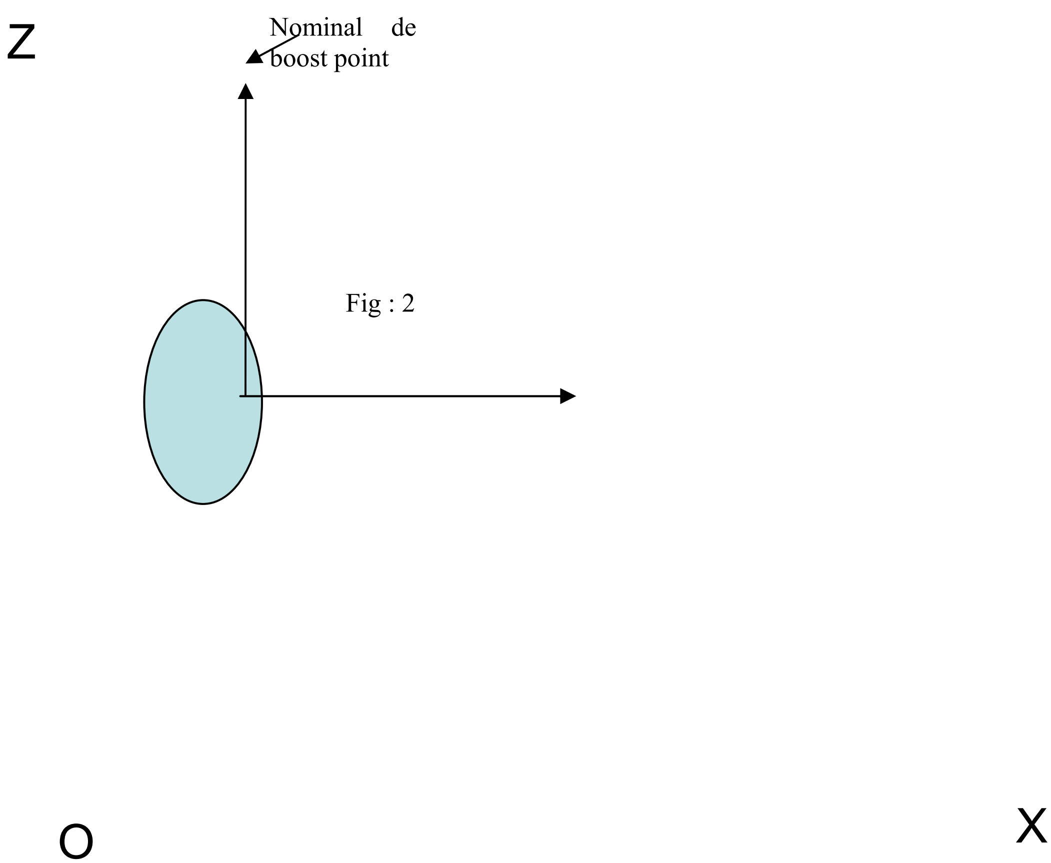

Fig : 2

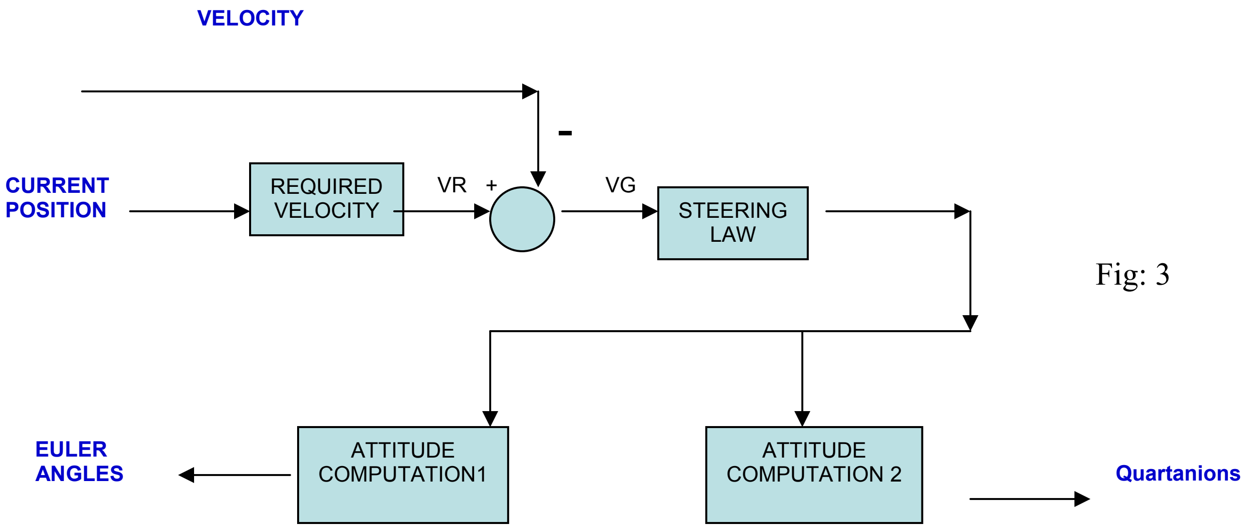

Fig: 3

fig:4

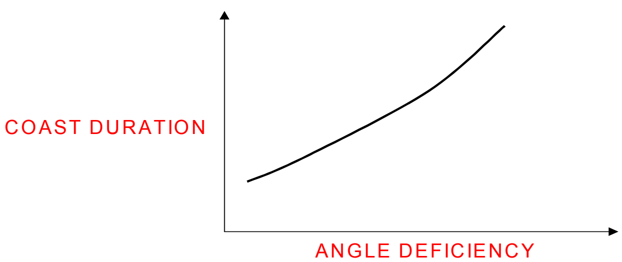

Table – 1 Entry conditions with VG guidance (no angle covered constraint)

Thrust	Altitude(km)	Velocity(m/s)	f.p. angle	Angle covered	Range (km)
Nominal	79.99	7935.39	93.65	119.9065	12754
+1%	79.99	7935.35	93.63	119.716	12722
-1%	79.99	7935.39	93.65	120.0878	12763
+3%	79.95	7935.44	93.65	119.3265	12682
-3%	79.99	7935.31	93.65	120.5162	12809
+5%	79.97	7935.44	93.65	118.9708	12648
-5%	80.0	7935.9	93.66	125.125	13009

Table – 2 entry conditions with vg guidance (angle to go constraint)

Thrust	Altitude(km)	Velocity(m/s)	f.p. angle	Angle covered	Range (km)
Nominal	79.99	7935. 09	93.65	119.9065	12748
+1%	79.99	7935.00	93.65	119.89	12752.5
-1%	79.99	7935.19	93.65	119.94	12747.5
+3%	79.95	7935.06	93.65	119.96	12747.9
-3%	79.99	7935.26	93.65	119.92	12749.0
+5%	79.97	7935.86	93.65	119.934	12750.0
-5%	80.0	7935.20	93.654	119.93	12746.0